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NAVORD REPORT 4093

STATIC STABILITY AND MAGNUS CHARACTERISTICS OF THE 5-INCH HIGH CAPACITY SPINNER ROCKET AT LOW SUBSONIC SPEEDS

18 AUGUST 1955

U. S. NAVAL ORDNANCE LABORATORY

WHITE OAK, MARYLAND

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Aeroballistic Research Report 304

STATIC STABILITY AND MAGNUS CHARACTERISTICS OF THE 5-INCH HIGH CAPACITY SPINNER ROCKET AT LOW SUBSONIC SPEEDS

Prepared by:

J. E. Greene

ABSTRACT: The static stability and Magnus characteristics of a 1.227 scale model of the 5-inch High Capacity Spinner Rocket have been determined for yaw angles of 0 degree through 28 degrees and for spin rates up to 10,000 RPM. The maximum diameter of the model was 6 inches. These tests were performed in the DTMB 8 x 10 foot low subsonic wind tunnel at speeds of 211 and 260 feet per second.

The results of this investigation show that the Magnus force and moment characteristics of the projectile are non-linear functions of the body spin rate and angle of yaw. In addition, the test results also show that high rotational speeds make the configuration less unstable, statically, and may, under certain conditions of spin and yaw, cause the rocket to be statically stable.

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In connection with the NOL Magnus program, tests on a 1.227 scale model of the 5-inch High Capacity Spinner Rocket at free-stream velocities of 211 and 260 feet per second have been completed in the DTMB 8 x 10 foot low subsonic wind tunnel. This work was done under task number NOL-A3d-453-1-55.

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By direction

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STATIC STABILITY AND MAGNUS CHARACTERISTICS OF THE 5-INCH HIGH CAPACITY SPINNER ROCKET AT LOW SUBSONIC SPEEDS

INTRODUCTION

1. The 5-inch High Capacity Spinner Rocket is a spin-stabilized rocket approximately 32 inches long and weighing about 50 pounds before burning. Eight rocket nozzles, canted at 12 degrees, impart a clockwise spin (as viewed looking from base to nose tip) of about 130 revolutions per second. Maximum range of the rocket is approximately 4,600 yards at a velocity of 780 feet per second.

2. As part of a current Naval Ordnance Laboratory program to study Magnus effects on typical projectile shapes at both subsonic and supersonic speeds, a low-speed wind-tunnel investigation of the 5-inch High Capacity Spinner Rocket was performed in the 8 x 10 foot atmospheric wind tunnel at the David Taylor Model Basin. Although these tests were performed at values of the spin parameter, $\omega d/2V$, up to and considerably in excess of the full-scale value*, or values which might be encountered under various "practical" conditions, the primary purpose of these tests was to investigate the Magnus and static stability characteristics of the configuration over a relatively large range of spin rate and angles of yaw.

Aerodynamic Symbols

A	body cross-sectional area based on maximum body diameter (square feet)
C_N	normal force coefficient = N/qA
$C_{\theta_{c.g.}}$	pitching moment coefficient referred to the center of gravity = $M_{\theta_{c.g.}}/qAd$
C_Y	lateral or Magnus force coefficient = Y/qA
$C_{\psi_{c.g.}}$	lateral or Magnus moment coefficient referred to the center of gravity = $M_{\psi_{c.g.}}/qAd$ (Magnus moment coefficient due to spin)
d	maximum body diameter (feet)

* $\omega d/2V$ = 1.0 for 6-inch test model and 10,000 RPM at 260 feet per second

$\omega d/2V$ = 0.2 for full-scale 5-inch High Capacity Spinner Rocket at 7800 RPM and 780 feet per second

Aerodynamic Symbols (continued)

$M_{\theta_{c.g.}}$	pitching moment about the center of gravity (inch - pounds)
ℓ	body length (feet)
$M_{\psi_{c.g.}}$	lateral or Magnus moment about the center of gravity (inch - pounds)
q	dynamic pressure (pounds per square foot)
V	airspeed (feet per second)
Re*	Reynolds number = $\rho V \ell / \mu$
N	normal force in the plane of yaw (pounds)
Y	lateral or Magnus force acting at right angles to the plane of yaw (pounds)
ω	body rotational speed (radians per second)-positive when clockwise as viewed by an observer looking upstream from model base
μ	absolute coefficient of viscosity of air (pound second per foot squared)
ρ	air density (slugs per cubic foot)
ψ	angle of yaw (degrees)

$$\left.\begin{array}{l} {}^{*}\ \mathrm{Re} \times 10^{-6} = 4.9 \text{ at } V = 260 \text{ feet per second} \\ \mathrm{Re} \times 10^{-6} = 4.0 \text{ at } V = 211 \text{ feet per second} \end{array}\right\} \text{based on total length of model}$$

Experimental Procedure

3. The models were mounted on an internal strain-gage beam which was attached to a stand positioned in the center of a turntable in the floor of the wind-tunnel test section. Holding the angle of attack at zero degree in the vertical plane, the model was yawed (in the horizontal plane) in steps of 4 degrees through a total angle range of -12 degrees through +28 degrees, a positive angle denoting displacement of the model to the right as viewed by an observer looking upstream in the tunnel.

4. To provide spin, a variable frequency motor was attached to the forward end of the balance beam and coupled to the forward section of the cylindrical afterbody. Spin rates were measured by a two-pole magnetic tachometer in the motor section.

5. Aerodynamic measurements below +16 degrees angle of yaw were taken in steps of 2000 RPM up to a maximum of 10,000 RPM. For angles of yaw above 16 degrees, intermediate values of model spin were used whenever deemed necessary.

6. All the model configurations were constructed of aluminum. Figure 1 shows the pertinent dimensions of tho 5-inch High Capacity Spinner Rocket model.

Data Reduction

7. All data were reduced to non-dimensional coefficients as shown in the section under Aerodynamic Symbols. For various test yaw angles, the zero spin data indicated small lateral forces (acting in a vertical plane relative to the tunnel) acting on the model. These forces were attributed to air loads resulting from asymmetrical positioning of the model in the pitch plane. The curves of lateral force and moment have therefore been shifted parallel to the coefficient axis until a zero lateral coefficient was indicated at zero spin rate. A table showing the magnitude of the shifts may be found in Table I of reference (a).

8. The accuracy of the test results presented in this report could not be subjected to a statistical analysis due to the lack of sufficient repeat data. However, on the basis of a few repeat runs, the average uncertainty of the plotted results has been estimated to be not greater than ± 0.04 in the coefficient values.

9. It should be noted in Figures 2 through 9, that no signs have been prefixed to the indicated angles of yaw except for the curves showing normal force and pitching moment coefficients. Taking into account the uncertainty of the data, the measured values of the aerodynamic forces at equal positive and negative angles of yaw up to and including 12 degrees were in such close agreement as to allow one curve to be representative of forces and moments at equal positive and negative angles. On this basis, the Magnus force and moment data at angles of yaw of 12 degrees and below are indicative of an absolute value and do not indicate the direction of the applied Magnus force or the sign of the Magnus moment. However, the correct sign of the Magnus moment at angles of 12 degrees and less may be obtained by examining the center of pressure plots, keeping in mind the direction and sign of the corresponding Magnus force which was consistent throughout the test, i.e., positive and directed upward for positive yaw angles as shown in the sketch under "Coordinate Axes and Sign Convention". The sign of the Magnus moment for data at 16 degrees and above is as shown in the various plots.

Results

10. Figures 2 through 9 show the Magnus and static stability characteristics of the 5-inch High Capacity Spinner Rocket at free-stream velocities of 211 and 260 feet per second. From Figures 2 and 6 it can be seen that the Magnus force is a smooth, non-linear function of the spin rate and angle

of yaw. Holding the spin rate constant, the Magnus force increases slowly with increasing yaw up to approximately 16 degrees; above this yaw angle the Magnus force increases rapidly to values, at 28 degrees yaw and 10,000 RPM spin rate, as high as 85 percent of the measured normal force at corresponding spin rates and angles of yaw.

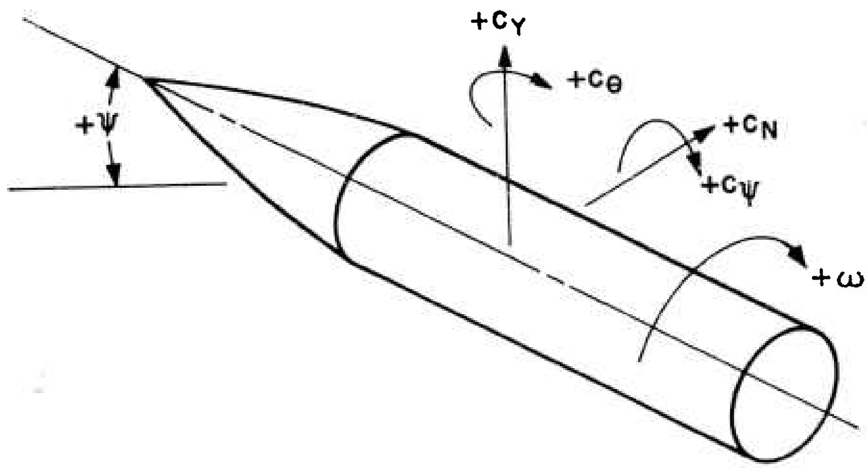
11. Figures 5 and 9 show the Magnus force center of pressure as a function of yaw angle for spin rates of 2,000 RPM and 10,000 RPM. Center of pressure positions at intermediate spin rates fall between these limiting curves. The Magnus force center of pressure is relatively insensitive to changes in spin rate but varies considerably with angle of yaw, moving rearward approximately one caliber in the yaw range $12^\circ \leq \psi \leq 28^\circ$.

12. Figures 4, 5, 8, and 9 show the static stability characteristics of the rocket at angles of yaw up to 28 degrees and spin rates to 10,000 RPM. It can be seen that the static stability varies appreciably with spin. The normal force increases up to values approximately twice those measured under no-spin conditions. It is interesting to note that increasing the spin rate increases the static stability (center of pressure moves aft) of this configuration and may, under certain conditions of spin and yaw, make the configurations statically stable. This does not mean, however, that service rounds operating at these "special" conditions would necessarily be dynamically stable.

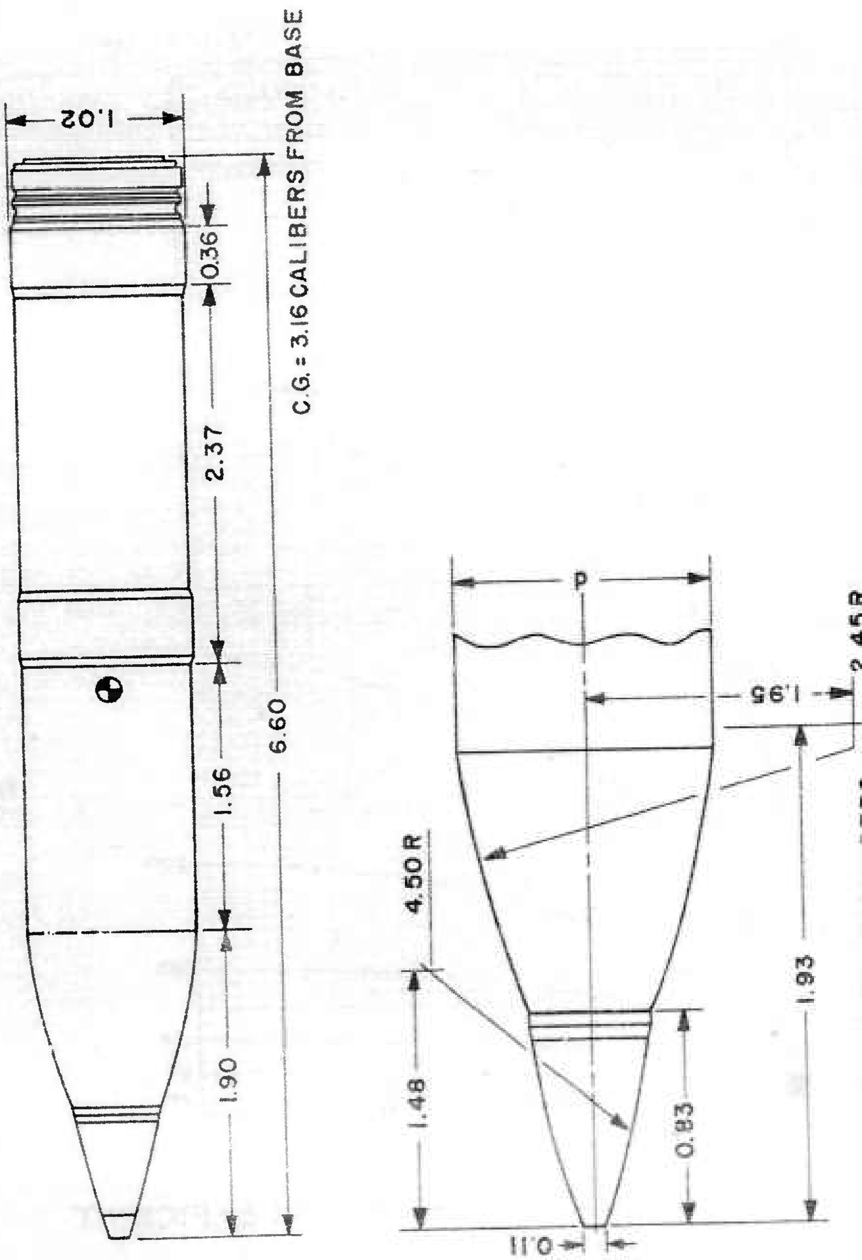
References

(a) Wright, John "Wind-Tunnel Investigation of a 1.227 Scale Model 5-Inch High Capacity Spinner Rocket Mk 10 Mod 0" TMB Report C-693 Aero Data Report 26 (Jan 1955) (Conf)

COORDINATE AXES AND SIGN CONVENTION



NOTE: POSITIVE DIRECTION OF COEFFICIENTS, SPIN, AND ANGULAR DISPLACEMENT IS DENOTED BY THE DIAGRAM ABOVE



NOTE: ALL DIMENSIONS SHOWN IN CALIBERS,
d = ONE CALIBER = 0.50 FEET

FIG.1 SKETCH OF THE 1.227 SCALE MODEL OF THE
5" HIGH CAPACITY SPINNER ROCKET

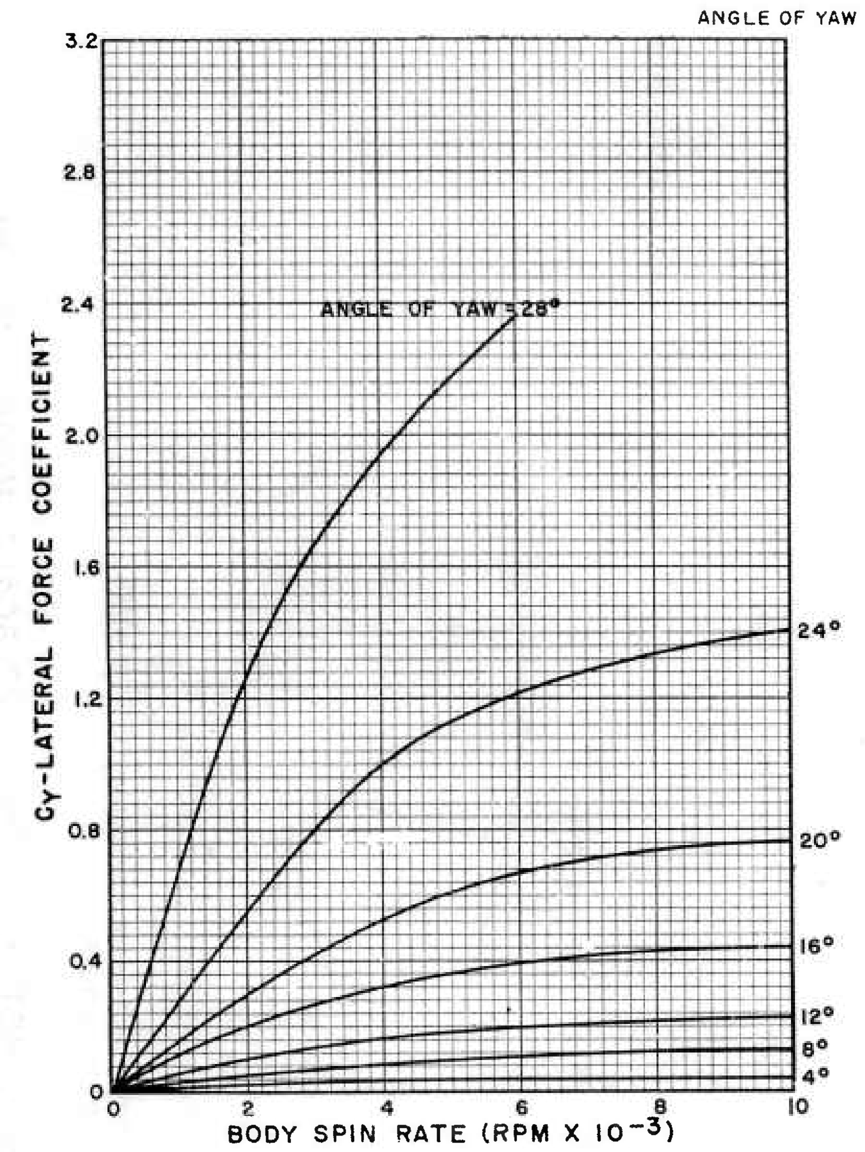


FIG. 2 VARIATION OF MAGNUS FORCE COEFFICIENT WITH BODY SPIN RATE
5" HIGH CAPACITY SPINNER ROCKET
V = 260 FT/SEC

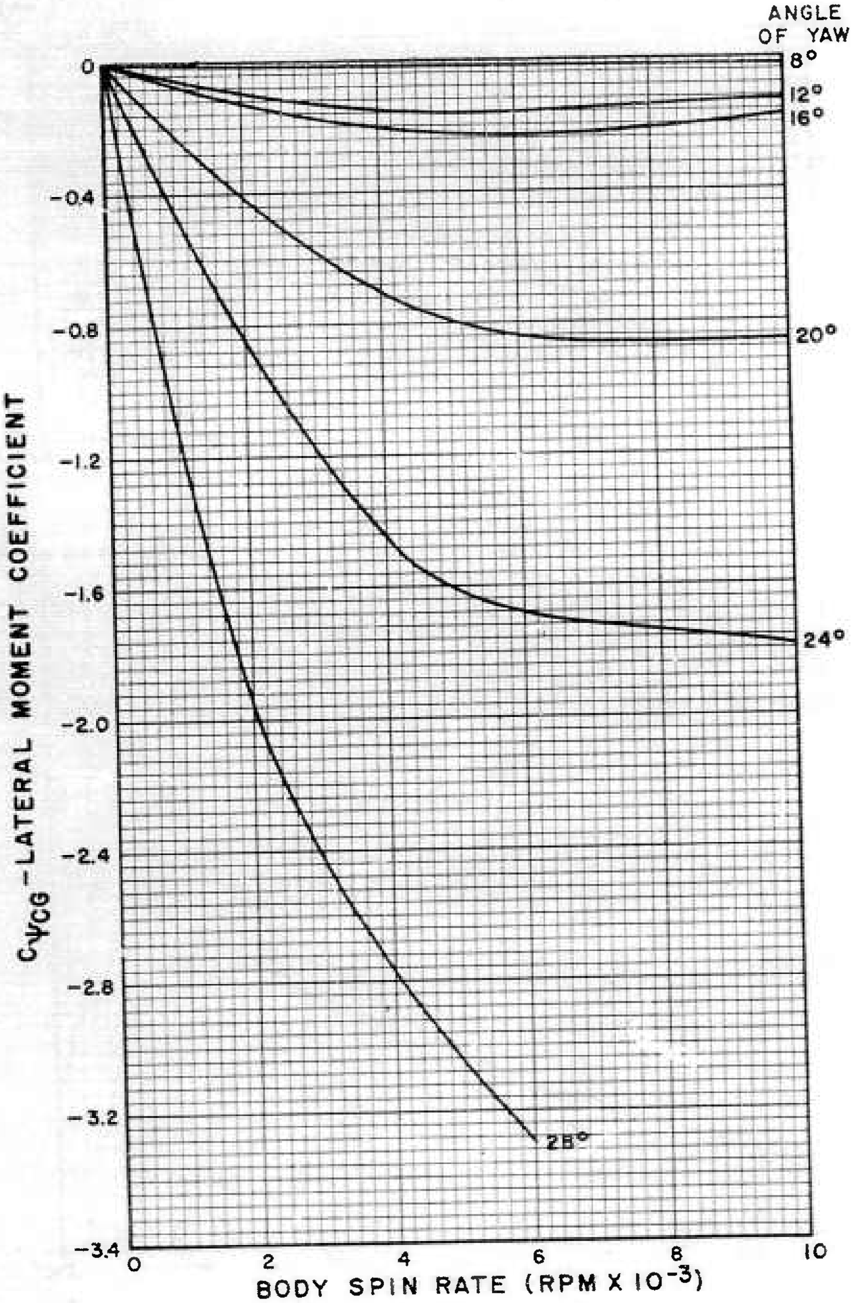
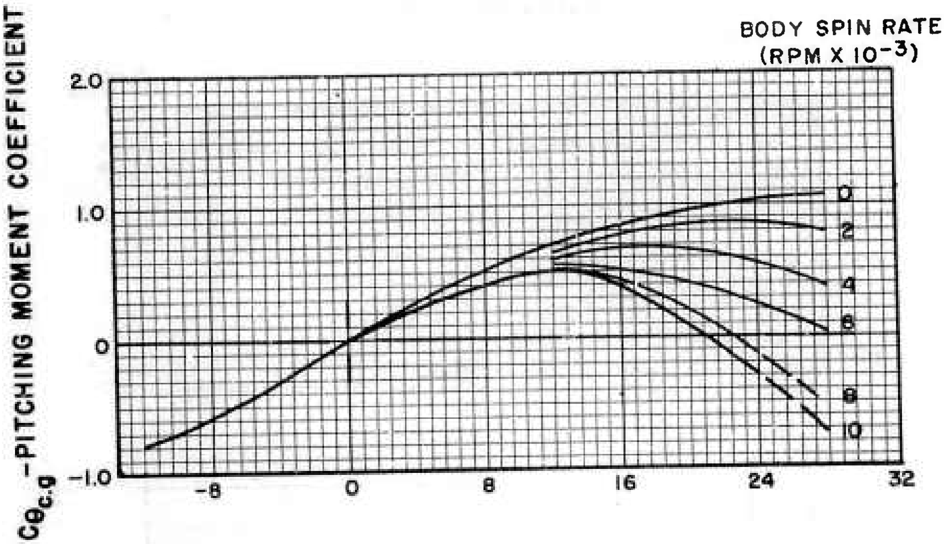


FIG. 3 VARIATION OF MAGNUS MOMENT COEFFICIENT WITH BODY SPIN RATE
5" HIGH CAPACITY SPINNER ROCKET
V = 260 FT/SEC



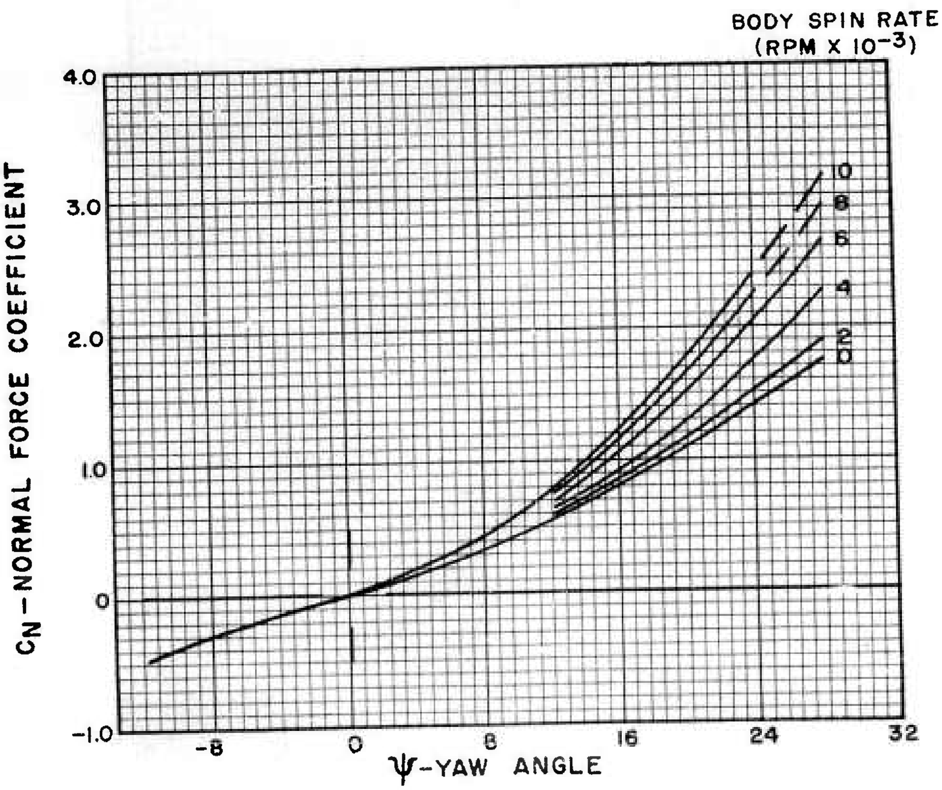


FIG. 4 VARIATION OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS WITH ANGLE OF YAW
5" HIGH CAPACITY SPINNER ROCKET
V=260 FT/SEC

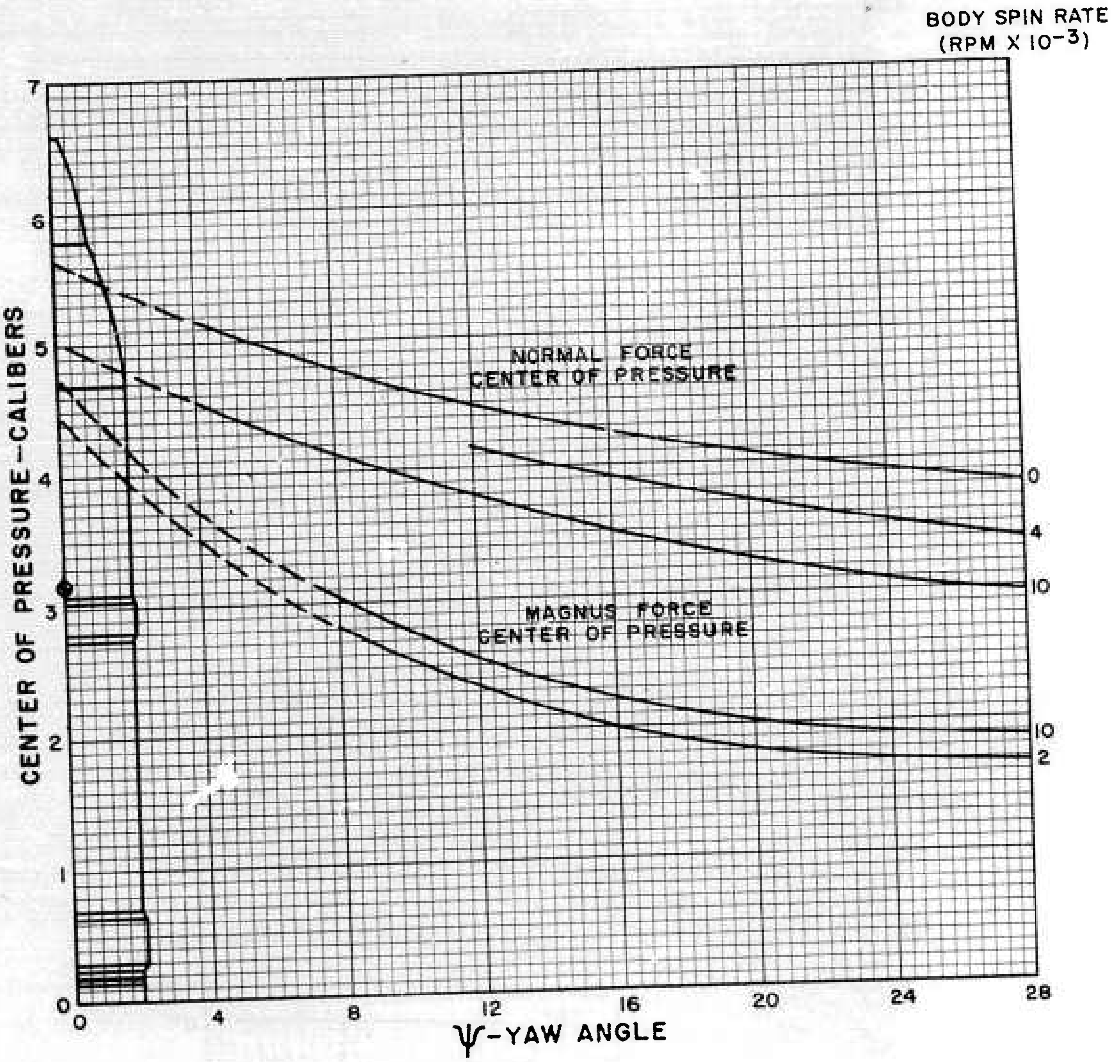


FIG. 5 VARIATION OF CENTER OF PRESSURE
WITH ANGLE OF YAW
5" HIGH CAPACITY SPINNER ROCKET
V = 260 FT/SEC

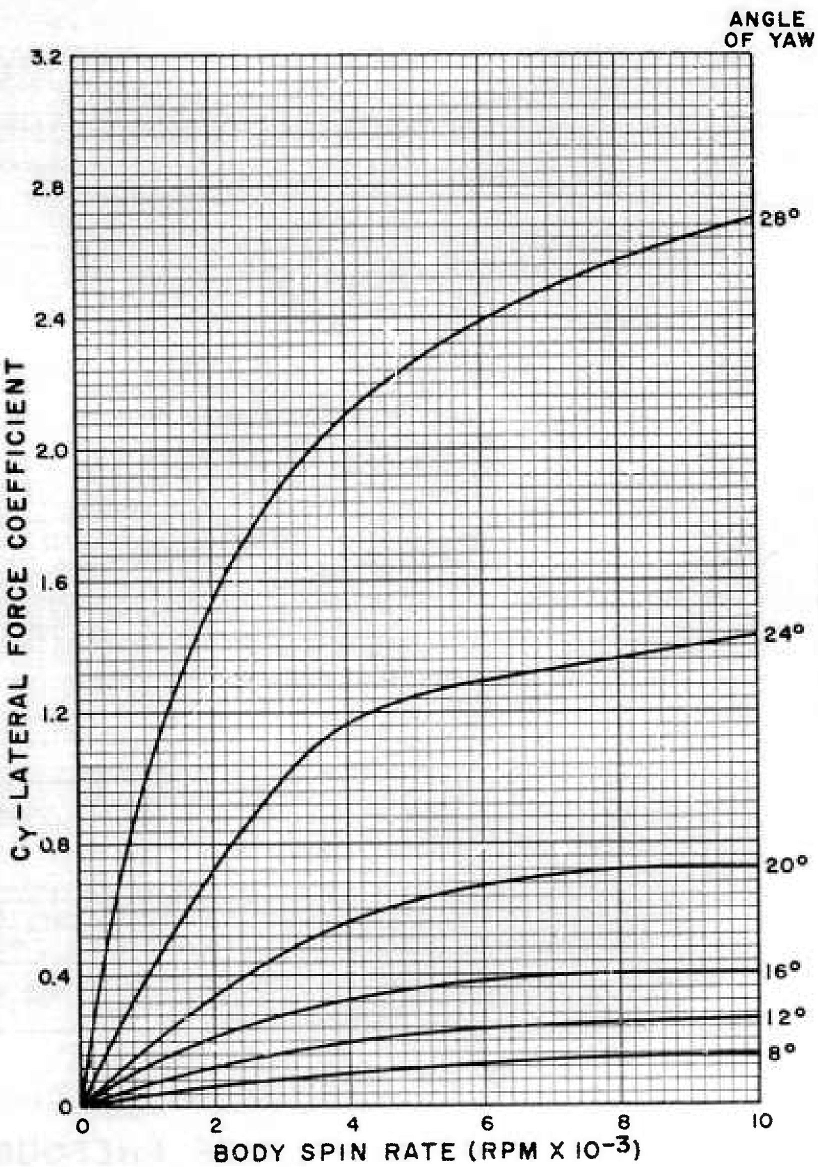


FIG. 6 VARIATION OF MAGNUS FORCE COEFFICIENT WITH BODY SPIN RATE
5" HIGH CAPACITY SPINNER ROCKET
V=211 FT/SEC

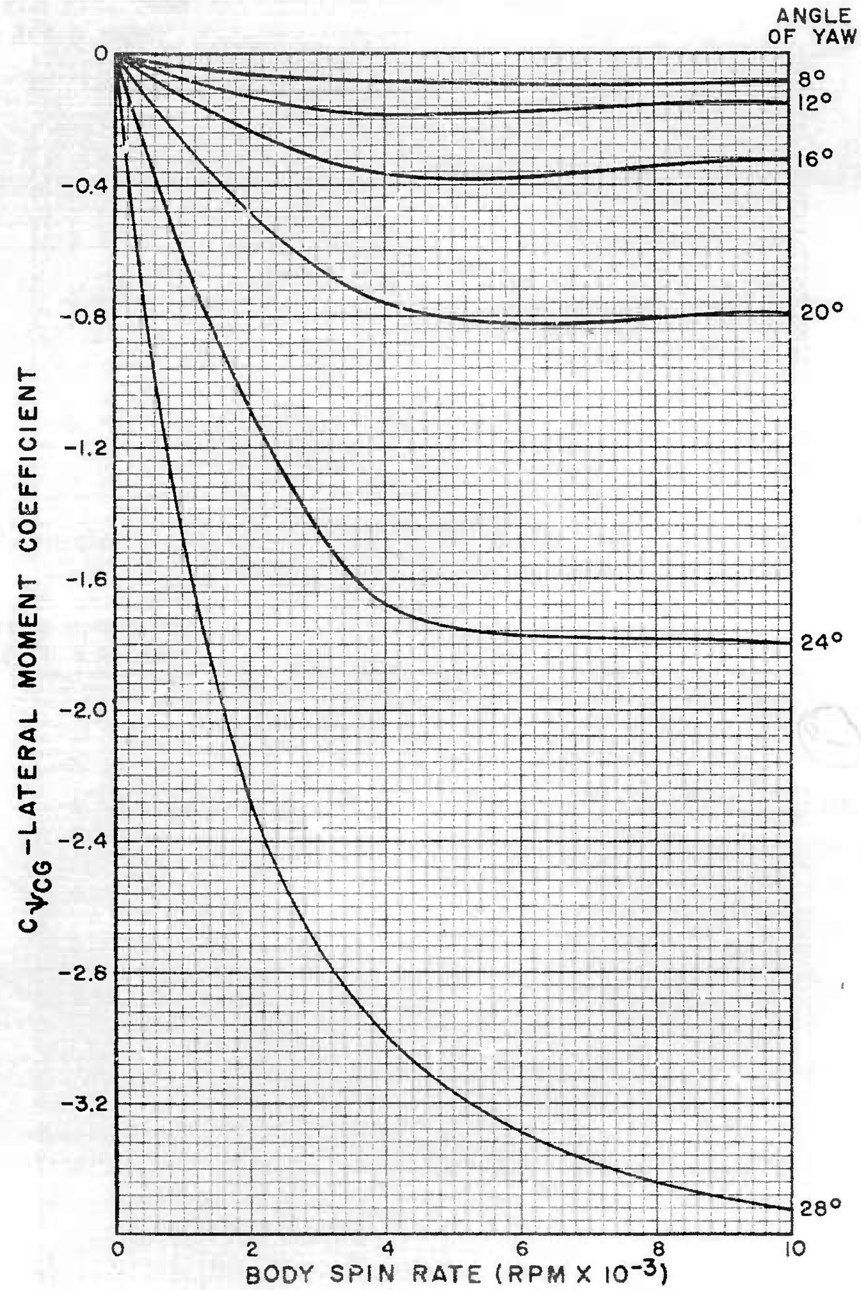


FIG. 7 VARIATION OF MAGNUS MOMENT COEFFICIENT WITH BODY SPIN RATE

5" HIGH CAPACITY SPINNER ROCKET
V=211 FT/SEC

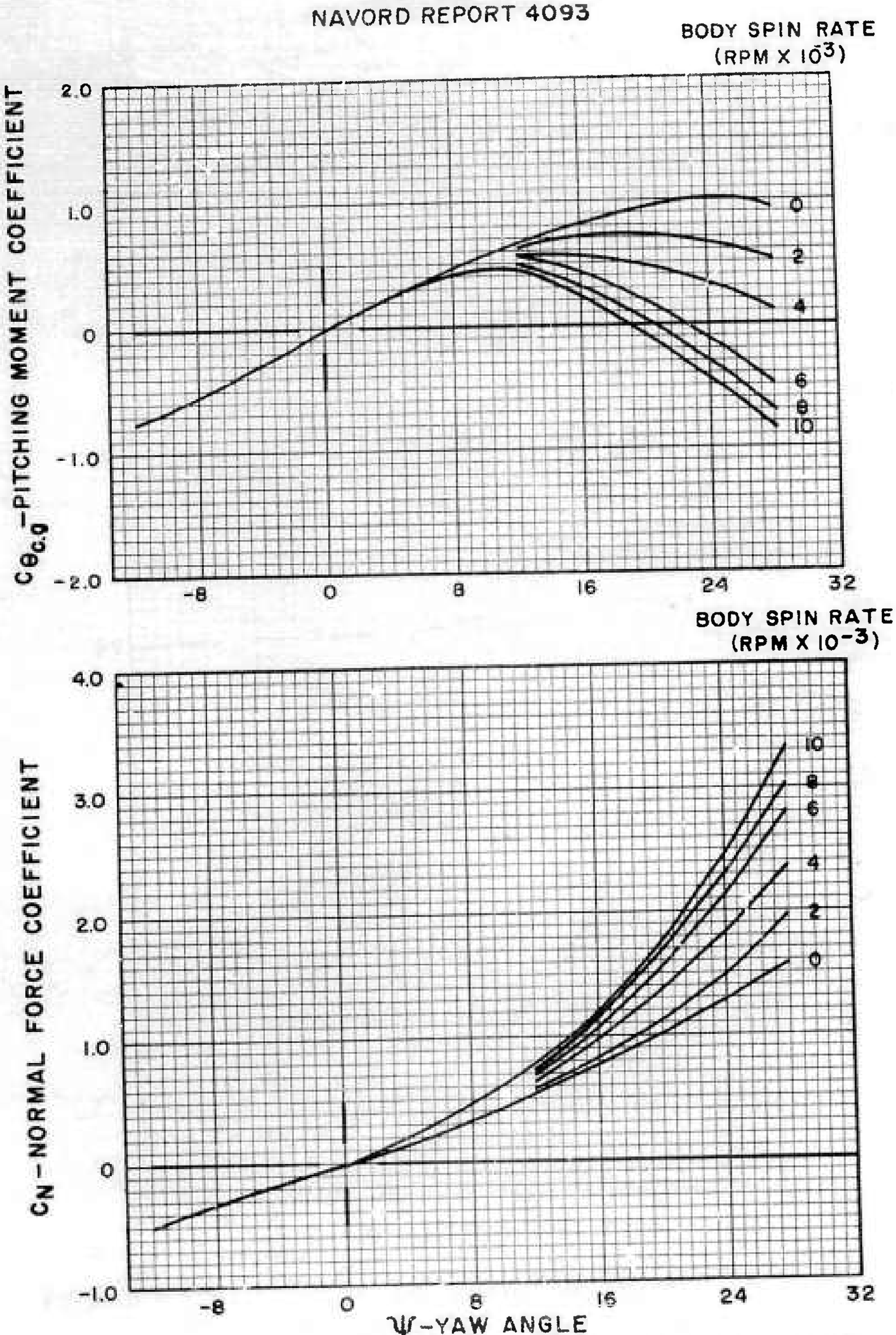


FIG. 8 VARIATION OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS WITH ANGLE OF YAW
5" HIGH CAPACITY SPINNER ROCKET V=211 FT/SEC

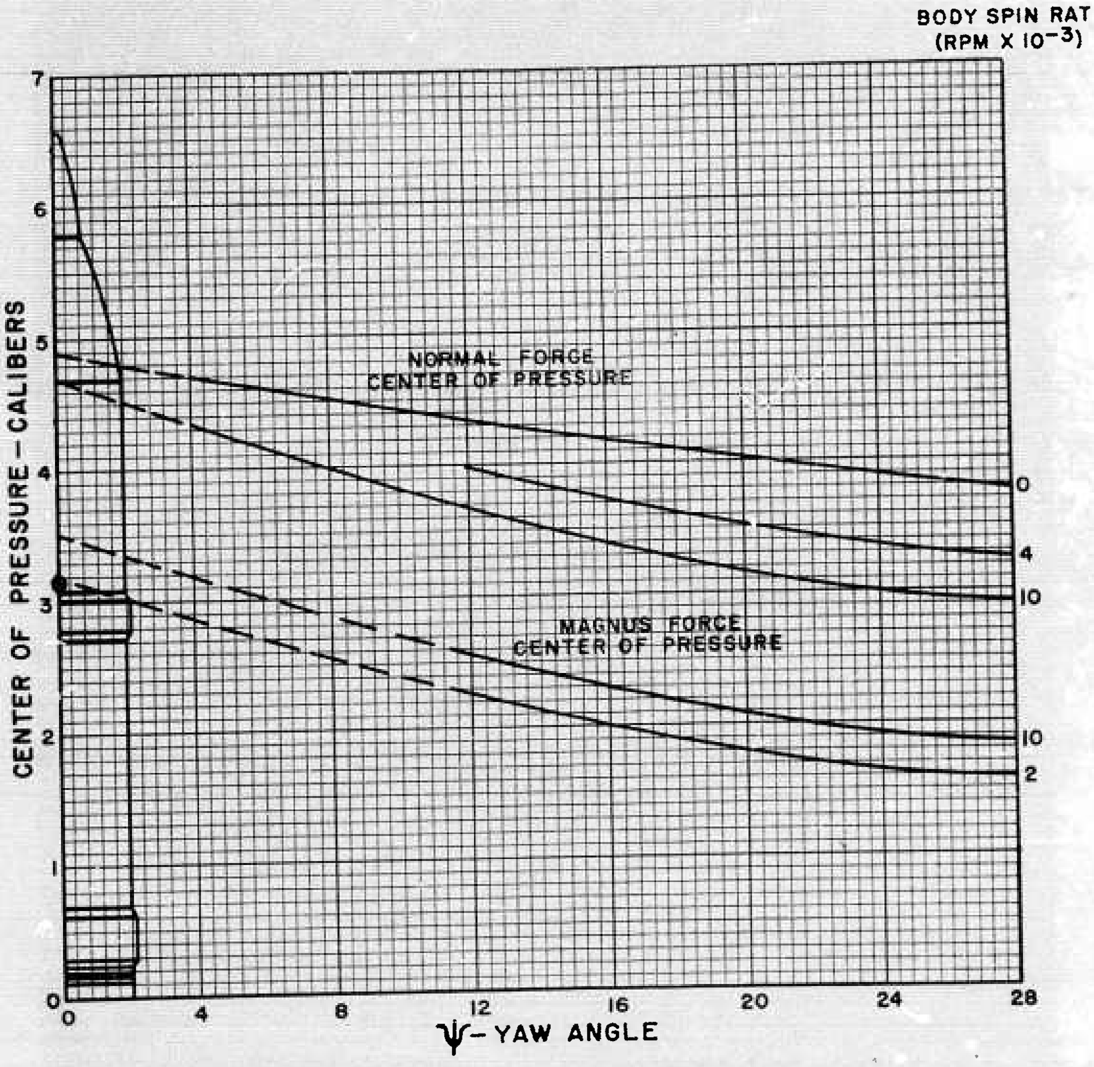


FIG. 9 VARIATION OF CENTER OF PRESSURE WITH ANGLE OF YAW
5" HIGH CAPACITY SPINNER ROCKET
V=211 FT/SEC

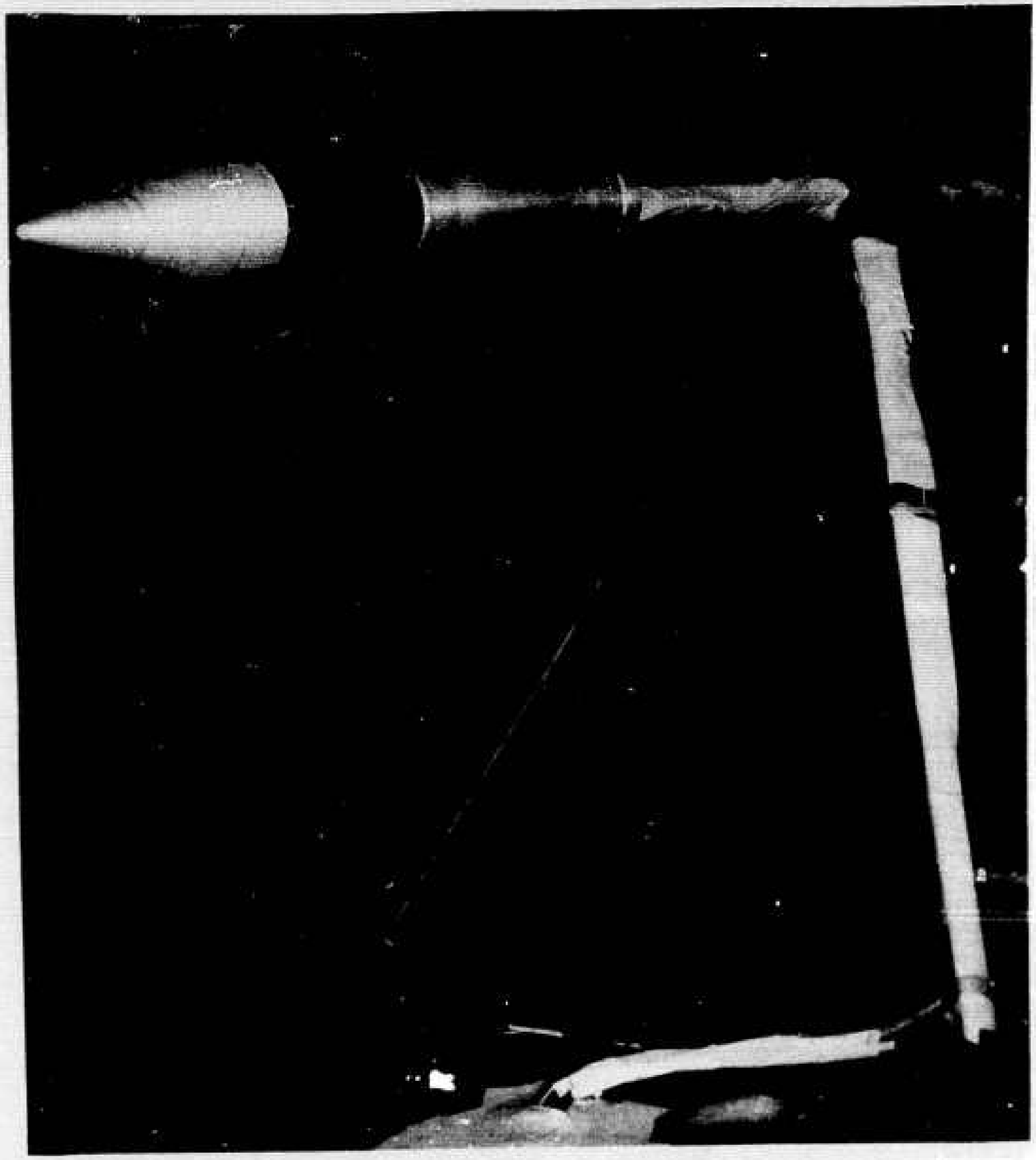


FIG. 10 5-INCH HIGH-CAPACITY SPINNER ROCKET MOUNTED ON TEST STAND FOR FORCE MEASUREMENTS